

NASA Technical Memorandum 101947

Expendable Launch Vehicle Transportation for the Space Station

(NASA-TM-101947) EXPENDABLE LAUNCH VEHICLE
TRANSPORTATION FOR THE SPACE STATION (NASA)
13 F CSCI 22B

N89-20179

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G3/16 0197252

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Prepared for the
39th Congress of the International Astronautical Federation
Bangalore, India, October 8-15, 1988

NASA

EXPENDABLE LAUNCH VEHICLE TRANSPORTATION FOR THE SPACE STATION

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Abstract

Logistics transportation will be a critical element in determining the Space Station Freedom's level of productivity and possible evolutionary options. The current program utilizes the Space Shuttle as the only logistics support vehicle. Augmentation of the total transportation capability by expendable launch vehicles (ELVs) may be required to meet demanding requirements and provide for enhanced manifest flexibility.

The total operational concept from ground operations to final return of support hardware or its disposal is required to determine the ELV's benefits and impacts to the Space Station Freedom program. The characteristics of potential medium and large class ELVs planned to be available in the mid-1990's (both U.S. and international partners' vehicles) indicate a significant range of possible transportation systems with varying degrees of operational support capabilities. The options available for development of a support infrastructure in terms of launch vehicles, logistics carriers, transfer vehicles, and return systems is discussed.

Introduction

The Space Station Freedom, being jointly developed by NASA, European Space Agency (ESA), Japan, and Canada, will usher in a new era for continuous scientific and commercial activities in low earth orbit (LEO). The space station will require a transportation infrastructure providing on-time, dependable support for crew, station systems, and experiments. Current plans call for support of Freedom exclusively by the National Space Transportation System (NSTS), i.e., Space Shuttle.

The NSTS, designed for manned LEO support missions, possesses unparalleled capabilities that are extremely important for the success and productivity of the space station. The uniqueness of the NSTS causes a high demand for its launch services. Demand for other missions such as planetary, military, and large observatories will limit the number of flights allocated to the Space Station Freedom program. Also, the operational complexities of the reusable systems (Orbiter, solid rocket boosters, Shuttle main engines, etc.) will limit the total number of flights available per year. These conditions have

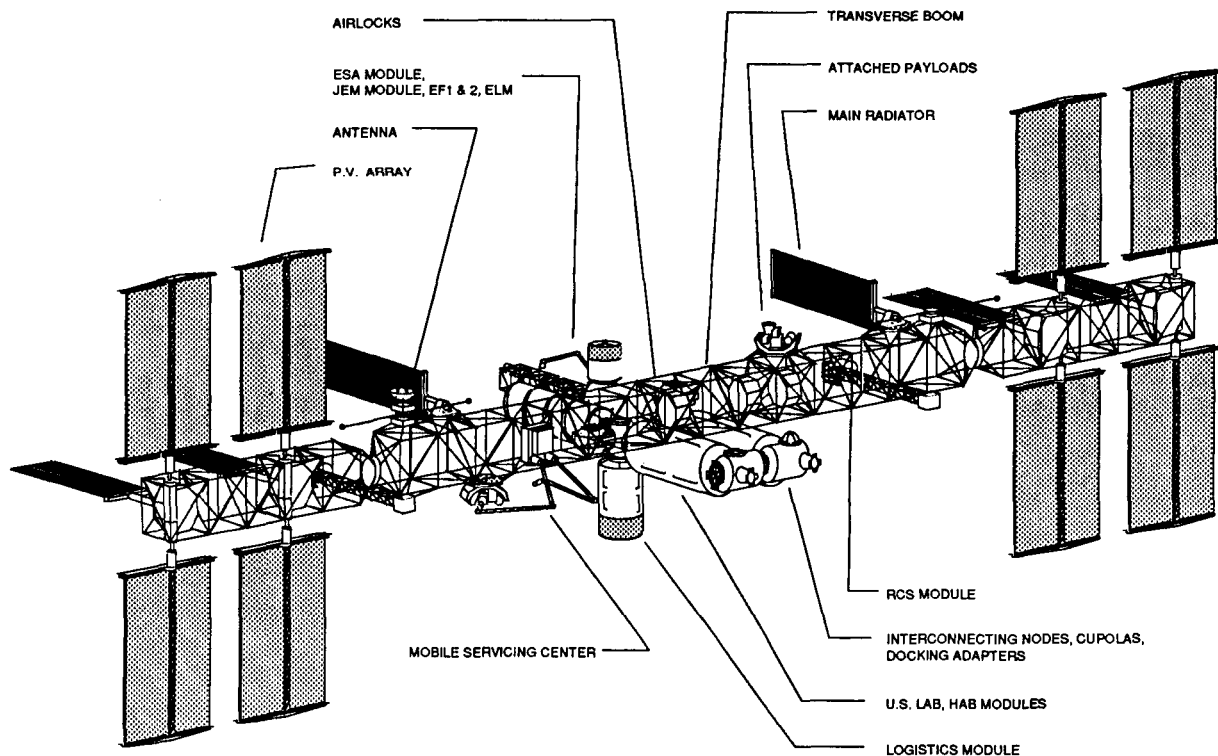


Figure 1 - Space Station Freedom

forced logistics planning for Freedom to be limited to five NSTS flights per year.¹ Limited availability of the NSTS will cause a constraint on the productivity of the space station. The users (scientists, corporations, entrepreneurs, and Government) will be limited by the ability to transport essential logistics by earth-to-orbit and return transportation.

The Shuttle-only policy had virtually phased-out the expendable launch vehicle (ELV) capability within the United States, which had been the mainstay of space launches for the past twenty-five years. But, due to a high demand for payload transportation to space and aggravation of the problem by the Challenger disaster, a change of policy to a mixed fleet has emerged. The use of ELVs as part of a mixed fleet to resupply Freedom can be a very valuable asset to the total logistics system. The unique capabilities of the NSTS (manned assistance, high power and thermal services, return capability) compared to more limited expendable vehicle capabilities decreases the likelihood that an ELV could duplicate NSTS's services. Nevertheless, the ELVs could augment the lift capacity of the NSTS to meet the demands of the crew, station operations, and its users. Thus, optimal launch vehicle utilization, efficient operational methods, impacts to the station and the launch vehicle, degree of commonality, and the net benefits have to be determined.

The use of ELVs for logistics support missions is questionable if the total system is to operate in a similar manner for the NSTS and an ELV. Efforts within NASA (1987 Joint Space Flight/Space Station Transportation Study and an ongoing study of the Role of ELVs in Space Station Post-PMC Logistics Operations) and the international community (Joint United States/ Japan Logistics Study and ESA's Ariane Transfer Vehicle Study) have started to address the issues of ELV usage for Freedom. The ELV options available, along with issues and potential problem areas will be addressed.

Potential for ELVs

Space Station Logistics Requirements

Logistics requirements have proven to be extremely difficult to determine with a high degree of confidence. Many factors contribute to this complex task, namely: (1) the infancy of long-term space habitation experience, (2) program changes, (3) broad and varying nature of customer payloads to be supported, and (4) lack of detailed designs for space station elements. These factors and many more have contributed to a fluctuation of requirements over the past few years. The requirements continue to be evaluated and revised as the program changes and new inputs become available.

Support of space station systems and crew, along with user experiment needs, can be categorized in terms of pressurized, unpressurized, and fluid logistics requirements. Summarized in Table 1 are the total annual steady-state resupply and return requirements as defined during the Joint Space Flight/Space Station Transportation Study.² Because of the repetitive nature of the logistics support, the usage of standard reusable carriers on the NSTS provides economies. These logistics carriers are a necessary addition to the requirements, but produce a tare to the net delivery capability to the space station. Estimated logistics element characteristics are summarized in Table 2.^{3,4}

NSTS Support

The current lift and return capability of the NSTS is shown in Table 3, with the appropriate reductions for Freedom's crew rotation, logistics element attachment hardware, berthing module, and space station program reserve required for a typical support mission.¹ Crew rotation may not be required on all five flights, with stay times of up to 180 days and a Freedom crew of eight, but is assumed since it is the most probable scenario.

Category	Pressurized MT		Unpressurized MT		Fluids/Gases MT		Total* MT	
	UP	DOWN	UP	DOWN	UP	DOWN	UP	DOWN
Support for:								
Station & Crew	16.1	13.9	3.5	3.5	0.7	0.0	20.3	17.4
Users	19.2	17.7	13.8	7.3	0.0	0.0	33.0	25.0
TOTAL (KLbs)	35.3 (77.8)	31.6 (69.7)	17.3 (38.1)	10.8 (23.7)	0.7 (1.6)	0.0 (0.0)	53.3 (117.5)	42.4 (93.5)

* Note: Numbers are NOT baselined program requirements. Reflect numbers used in Joint Space Flight/Space Station Transportation Study

Table 1 - NASA Transportation Study Annual Logistics Requirements²

Characteristics Logistics Element	Length		Diameter		Tare Weight		Payload Capacity	
	m	ft	m	ft	MT	Klbs	MT	Klbs
Pressurized Logistics Module (PLM)	6.1	20.1	4.4	14.5	7.6	16.7	10.0	22.0
Unpressurized Logistics Carrier (ULC)	2.4	8.0	4.4	14.5	1.1	2.4	2.9	6.3*
Dry Cargo Container (each)					0.08	0.17	0.2	0.5
Fluids Subcarrier					1.0	2.3	1.5	3.2
Japanese Experiment Logistics Module								
ELM Pressurized Section	4.0	13.1	4.0	13.1	3.2	7.1	5.0	11.0
ELM Exposed Section	1.5	4.8	2.5	8.2	1.7	3.7	4.0	8.8

* Note: Assumes ULC with 12 Dry Cargo Containers installed (Tare weight = 2.06 MT).

Table 2 - Logistics Carrier Characteristics^{3,4}

The pressurized cargo demands the most stringent requirements on the launch vehicle in terms of power, thermal control, and late access. Also, due to the large tare for pressurized payloads, high lift capability is essential. Thus, the manifest of pressurized cargo on NSTS would be most prudent. Using this assumption for a representative manifest based on five NSTS (OV-103 class) flights, logistics element weights and preliminary requirements would indicate that most of the pressurized cargo can be accommodated (Figure 2). However, all of the unpressurized cargo, including fluids and gases, and the Japanese Experiment Logistics Module (rotational requirement for 18 month intervals) exceed the five NSTS per year fleet resupply capability.

Obviously, the current transportation capabilities of the NSTS alone cannot support steady-state space station requirements. The utilization of Freedom will be constrained by the capabilities of the total launch system. Reduction in the scope of the space station and limitations on its experimental and production activities will defeat the main purpose for its existence. Additional NSTS flights, logistics element weight reduction, enhancements to the NSTS lift capacity, and/or augmenting NSTS lift capability with ELVs are essential.

ELV Option

Concerns exist over the ability of the current system to meet the projected demand. These concerns are increased if requirements increase, as the systems are better defined, and as the station grows. Ongoing studies to determine potential carrier weight reductions may provide for a more efficient system, but offer only minor relief. Additional

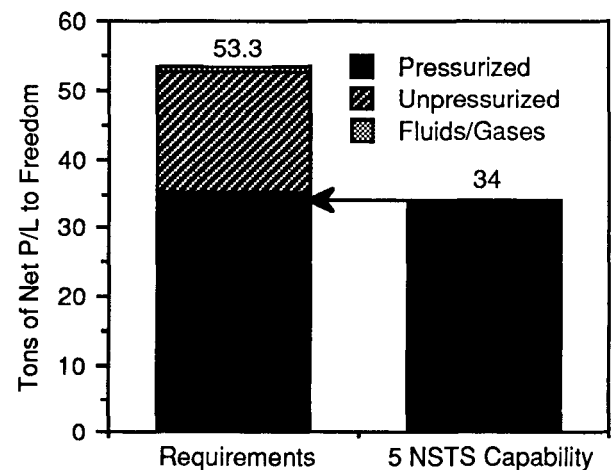


Figure 2 - Requirements versus Capability

NSTS (OV-103, 104, 105)	RESUPPLY		RETURN	
	KG	LBS	KG	LBS
220 NMI (28.5°) Capability ¹	+17,930.	+39,530.	+18,824.	+41,500.
Tares:				
Crew Rotation	-612.	-1,350.	-612.	-1,350.
Attachment Hardware	-510.	-1,125.	-510.	-1,125.
Berthing Module	-1,497.	-3,300.	-1,497.	-3,300.
Program Reserve	-907.	-2,000.	-907.	-2,000.
TOTAL	+14,404.	+31,755.	+15,298.	+33,725.

Table 3 - NSTS Launch and Return Capability

NSTS flights will cause a monopoly by the space station on the valuable NSTS resources that will be essential for other programs. Enhancement to the NSTS lift capability provides an excellent near-term solution. NASA is currently pursuing Advanced Solid Rocket Motor upgrades for the NSTS with a 5,443 kg (12,000 lb) increase goal.² This enhanced capability will capture most of the weight requirements, but volume may become the constraining factor. Limitation on the growth potential of the space station will still be present without additional NSTS flights. A more resilient option is the use of ELVs to supplement the NSTS.

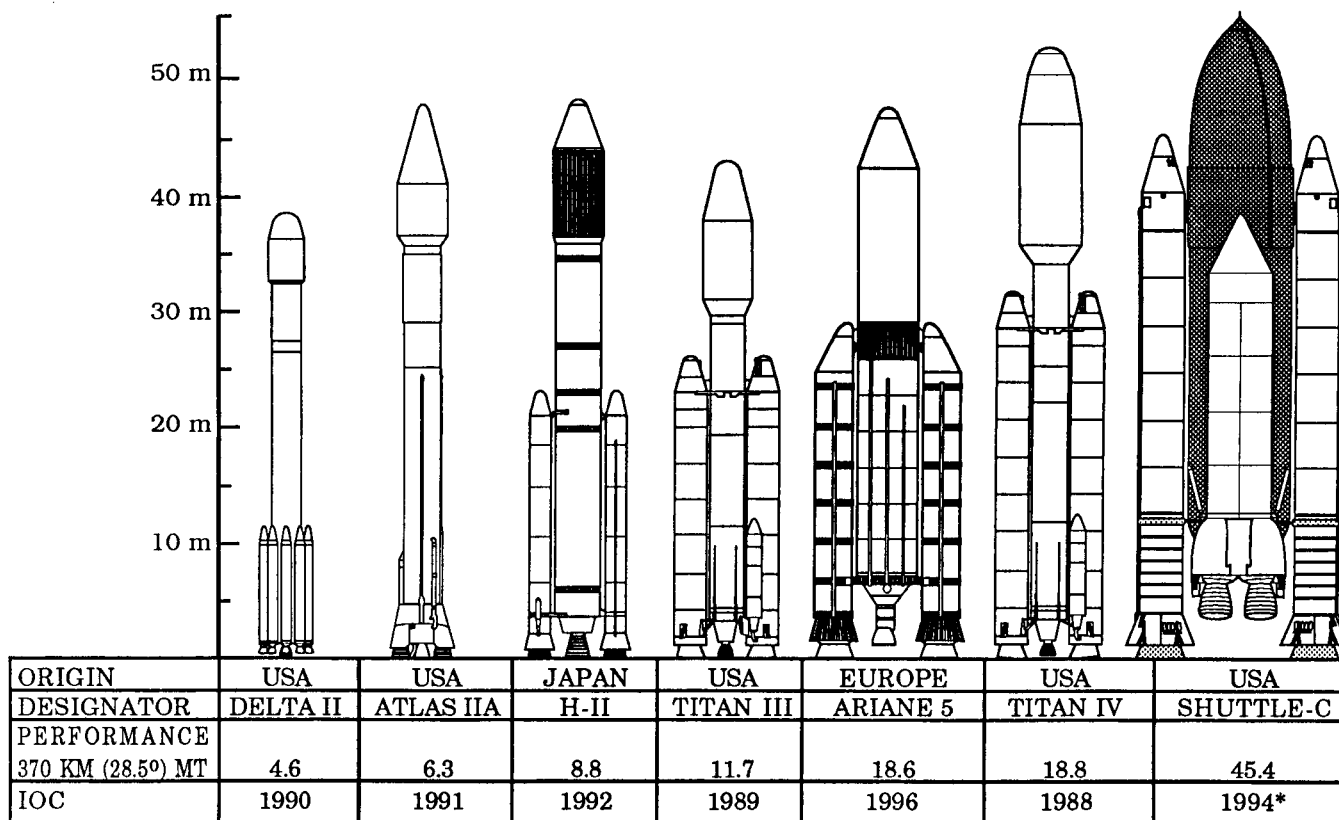
Use of ELVs with the NSTS would allow for a logistics system that could provide a division of logistics payloads best suited for the launch vehicles' design and capabilities. For example, the NSTS could be utilized strictly for rotating crews, delivering payloads with high resource requirements, and returning elements to Earth. ELVs can provide effective space launch capability for space station logistics missions by allowing: (1) added payload to orbit capability, (2) NSTS schedule relief, (3) high payload frequency support, (4) reduced risk by off-loading hazardous payloads, (5) manifest flexibility,

(6) de-coupling of manned launch schedules from cargo delivery requirements, (7) greater flexibility for space station growth, and (8) provide possible backup capability.

The use of ELVs poses several problems. First, various ELVs with different payload envelopes, launch environments, payload interfaces, and lift capabilities will exist. Planning for all possibilities may not be practical. Second, commonality with the NSTS will be difficult, or impossible in some cases. Dedicated ELV logistics elements may be required. Third, payloads requiring power or special conditions during launch may need to be excluded from launch on an ELV. Fourth, a transfer vehicle to deliver the payload will be required. Last, and possibly most critical, the enhancement of lift capability by ELVs does not increase the return capability and may create a need for alternate logistics return or disposal systems.

Launch Vehicles

Once a dying breed, the ELV market is now a thriving market with industry offering commercial launch services. A large fleet of mid- to large-



* IF FUNDING IS APPROVED

Figure 3 - Canidate Expendable Launch Vehicles for Freedom Support

class ELVs will exist in the space station era of the mid to late 90's, relying on advanced variations of reliable workhorses of the past along with new designs. The candidate configurations most likely to be utilized for a Freedom mission are depicted in Figure 3. The United States industrial products are the Delta II, Atlas IIA, Titan III, Titan IV, and possibly the Shuttle-C. The international partners are offering the Ariane 5 and H-II. Agreements between all international partners will allow for logistics support provided by their corresponding launch vehicles. This agreement allows for the manifest of space station cargo on an H-II and Ariane 5.

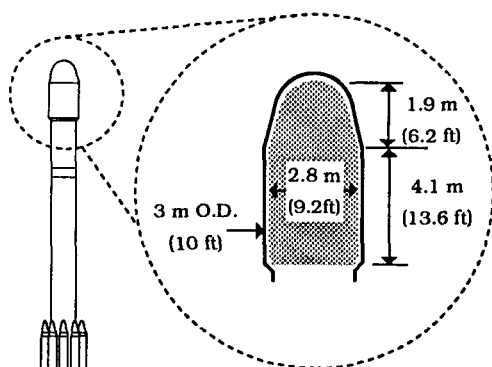


Figure 4 - Delta II 3m Fairing

Delta II

The commercial Delta II launch vehicle, developed and manufactured by McDonnell Douglas Astronautics Company (MDAC), comes from a very reliable evolutionary family consisting of a series of enhancements dating back to 1960. The Delta II will be a commercial version of the Medium Launch Vehicle (MLV-I) configuration being developed for U.S. Air Force needs. The Delta II vehicle configuration consists of a liquid propellant (oxygen/kerosene) first stage augmented by nine graphite epoxy solid rocket motors, a structural interstage, bi-propellant second stage, and various fairing options. The Delta II three meter (10 ft) fairing (Figure 4), being developed for the Roentgen Satellite (ROSAT) mission, is the most probable available option for Freedom support. A launch from the Eastern Test Range (ETR) from either pads 17A or 17B can deliver an estimated 4,630 kgs (10,200 lbs) to 370 km (200 nmi) circular orbit.⁵ (Freedom's baseline orbit is 407 kilometers. However, currently configured ELVs cannot enter the 37 km command and control zone.)

Atlas IIA

The Atlas IIA launch vehicle, as a commercial version of the U.S. Air Force's Medium Launch Vehicle II (contract with General Dynamics), will be an upgraded version of the current commercial Atlas I configuration, based on the Atlas/G Centaur workhorse of the 60's and 70's. The Atlas IIA vehicle consists of a one and one-half Atlas stage and the Centaur D-1A cryogenic (LOX/LH₂) upper stage. The Atlas stage consists of a central sustainer engine flanked by two jettisoned booster engine sections, a liquid propellant (oxygen/kerosene) tank section, and an interstage adapter section. The Atlas IIA will offer a four meter (14 ft) payload fairing as shown in Figure 5. This configuration launched from ETR's space launch complex 36B (36A and 13 also possible) is estimated to deliver 6,305 kgs (13,900 lbs) to a 370 km circular orbit. An enhancement of approximately 320 kgs (700 lbs) is being pursued by using two small strap-on Castor II solid rocket motors with a designation of Atlas IIAS.⁶

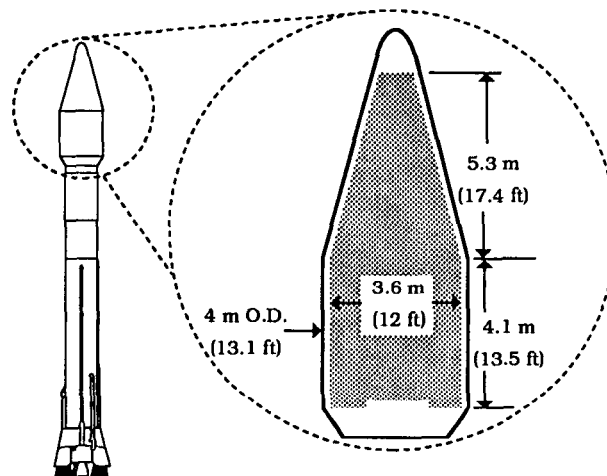


Figure 5 -Atlas IIA Large P/L Fairing

Titan III

The Titan family of launch vehicles from the Martin Marietta Corporation, was the U.S. Air Force's large lift system for more than 20 years, as well as a vital manned (Titan II/Gemini) and unmanned system for NASA. The commercial Titan III consists of a two-stage core vehicle utilizing the same storable liquid propellants for both stages, along with two large five and a half segment solid rocket boosters. The solid rocket boosters are ignited for lift-off with the first stage engines ignited at altitude. A four meter payload fairing for both dual

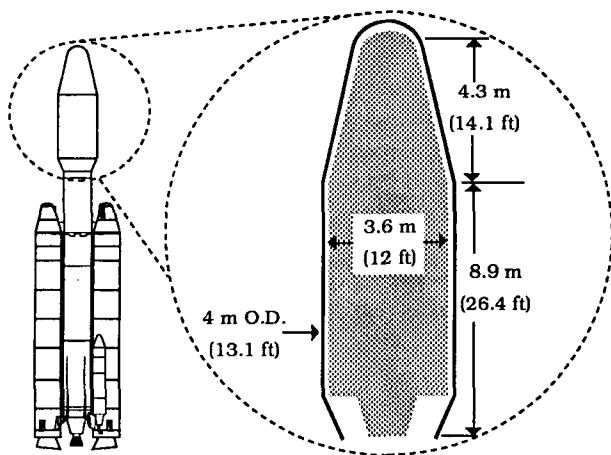


Figure 6 - Titan III Fairing

and dedicated spacecraft configurations will be offered. The single payload configuration with no upper stage (NUS) is the most likely candidate for a space station mission (Figure 6). The Titan III/NUS configuration is estimated to directly insert 11,700 kgs (25,800 lbs) to 370 km orbit from ETR's launch complex 40.⁷ A restart capability for the Titan III second stage engine could substantially increase its capability (approximately 2270 kgs).

Titan IV

The Titan IV is an improved version of the Titan III space launch system, with a stretched first stage and a modified second stage, seven-segment solid rocket motors, and a fairing that can accommodate NSTS payloads. The Titan IV is being developed and built for the U.S. Air Force with three configurations: (1) a Centaur upper stage, based on the cancelled Centaur G-prime developed for the NSTS, (2) a solid propellant Inertial Upper Stage

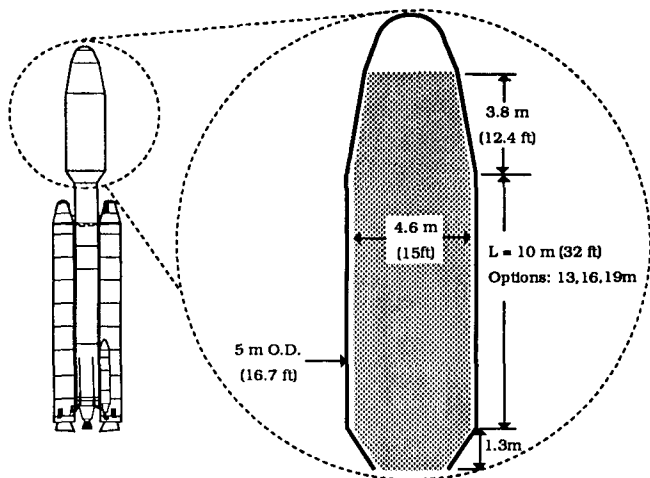


Figure 7 - Titan IV Fairing

(IUS), and (3) no upper stage. The large Centaur and IUS upper stages are not required for low Earth orbit deliveries. Thus, a Titan IV/NUS configuration is the most appropriate. The five meter (16.7 ft) bulbous fairing for the Titan IV has various length options starting with an overall length of 17 meters (56 ft) to a possible 26 meters (86 ft) in three meter increments (Figure 7). The direct insertion of 18,770 kgs (41,300 lbs) to 370 km circular is predicted for the Titan IV with upgraded solid rocket motors from ETR's space launch complex 40 or 41.⁷ Again, an enhancement to the second stage engine could provide a performance improvement.

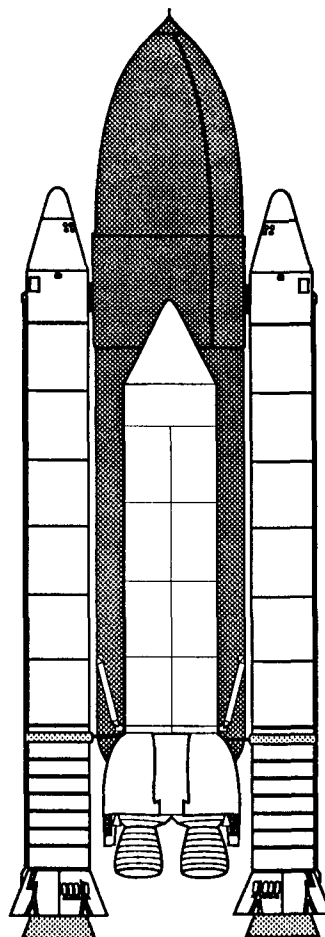


Figure 8 - Shuttle-C Concept

Shuttle-C

The Shuttle-C has been under consideration by NASA for the past few years as a means of providing the United States with a heavy lift launch capability by 1994 at relative low development risk and cost. A baseline concept has been developed that utilizes the current Shuttle's external tank, solid rocket boosters, main engines, and the boattail (Figure 8). The Shuttle-C would provide a 25 meter

(82 ft) payload carrier that included a strongback to support payloads similar to the Space Shuttle. Using the same launch pads as the Space Shuttle, the Shuttle-C will be designed to deliver 45,360 kgs (100,000 lbs) to the space station using two main engines and 70,300 kgs (155,000 lbs) with three.⁸

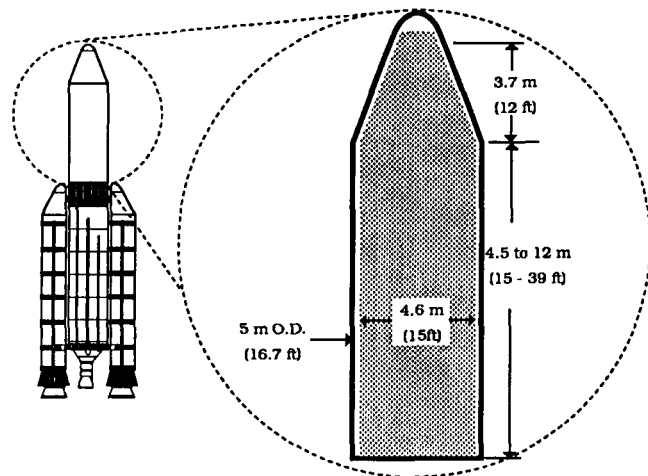


Figure 9 - Ariane 5 Fairing

Ariane 5

The Ariane series of launch vehicles has proven to be highly competitive in the satellite delivery business. The Ariane 5, the latest development vehicle in the series, is being designed to support various low earth orbit missions including Freedom, launch of the Hermes spaceplane, as well as the typical geostationary commercial satellite missions. The Ariane 5 vehicle is envisioned to consist of a cryogenic (LOX/LH₂) first stage (H155) augmented by two recoverable solid rocket boosters (P230), a storable propellant second stage (L5), and a payload fairing designed for compatibility with NSTS payload diameters (Figure 9). Ongoing studies are investigating a second stage variation specifically designed for the Freedom mission, designated as the Ariane Transfer Vehicle. An anticipated launch from Guiana Space Center in Kourou, French Guiana, has a goal to place 18,000 kgs (39,680 lbs) into low earth orbit (550 km).⁹

H-II

The new H-II launch vehicle being developed by the National Space Development Agency of Japan (NASDA) will become Japan's main launch vehicle for the 1990's. The H-II will be a two-stage rocket consisting of a cryogenic (LOX/LH₂) first and second stage with two large solid rocket boosters for first stage thrust augmentation. The vehicle

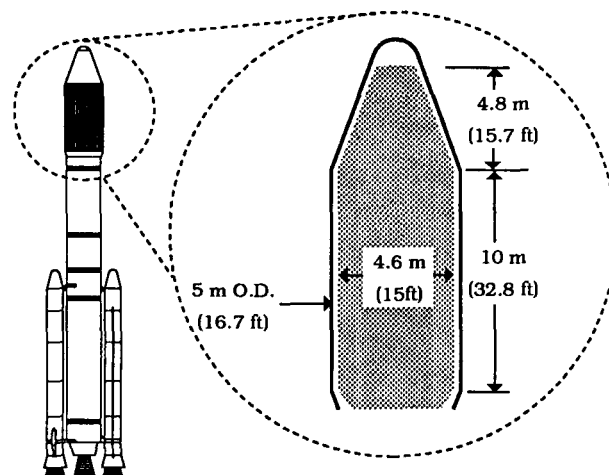


Figure 10 - H-II Fairing

will initially employ a four meter diameter payload fairing with the potential for an increase to five meters (Figure 10). For a Freedom resupply mission, it is estimated that the H-II can deliver 8,800 kgs (19,360 lbs) when launched from Tanegashima Space Center.¹⁰

Small Launch Vehicles

The small commercial launch vehicle market has experienced an introduction of numerous concepts, proposals, and development programs of low cost alternatives, such as the Pegasus, Liberty, Industrial Launch Vehicle, etc. These vehicles offer limited lift capability and very constraining payload envelopes for Freedom support. Continuous resupply of the station by small vehicles may not be appropriate, but their usage in a quick response mode should be given future consideration.

Transfer Options

A major element of the ELV's mission to Freedom is the final rendezvous and docking of the payload. The transfer vehicle used must meet the space station requirements in the Command and Control Zone (CCZ). The CCZ boundary is 37 km (20 nmi) in either direction along the space station velocity vector with its vertical and horizontal dimensions equal, and out-of-plane dimension of nine kilometers (5 nmi) in either direction (Figure 11). Freedom will have control authority of all unmanned vehicles within the CCZ and they must utilize the Global Positioning System receiver and processor for state vector computation with direct radio frequency links to the station.¹¹

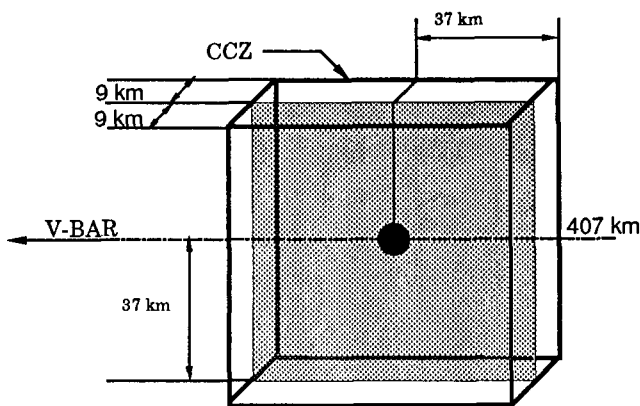


Figure 11 - Command & Control Zone (CCZ)

Transfer vehicle options to meet the Space Station requirements include: (1) the Orbital Maneuvering Vehicle (OMV), (2) upgrade of ELV's final stage, (3) upgrade of current propulsion modules, and (4) a new transfer vehicle.

Orbital Maneuvering Vehicle

The OMV is an excellent candidate for retrieval of logistics payloads delivered by ELVs in a stable orbit. The OMV (Figure 12) is being developed by TRW for NASA to extend the reach of the NSTS in low earth orbit. The OMV is composed of two major elements; the Short Range Vehicle (SRV), capable of performing solo low energy missions, and an inserted Propulsion Module (PM). Three separate propulsion systems are used along with sophisticated avionics with rendezvous and docking capability. The initial OMV will function out of the Shuttle, but the design allows for refueling and servicing while in space (up to 18 months). The large mass and diameter of the OMV (Table 4) prohibits its launch on most ELVs and is impractical to launch every mission. The need exists to base the OMV in space, preferably at the space station as opposed to free-flying, to utilize its potential. The OMV will re-

quire the logistics payload, or carrier, to provide a three point docking interface or a remote manipulator system (RMS) end effector for retrieval. The three point docking interface will be required for the large Freedom payloads.

Several issues exist with this option. First, the OMV is not presently part of the Freedom program, and thus, berthing accommodations must be determined. Second, OMV support requirements must be integrated into the total logistics requirements. The last significant issue is the long-term stabilization requirement (up to 60 hrs) necessary to assure successful link-up with the OMV. ELVs typically do not provide this capability. The ELV or carrier will need avionic and propulsion equipment to maintain a stable orbit. This could be developed, but the difference between developing this capability and the equipment necessary for the carrier to fly directly in to station may be small.

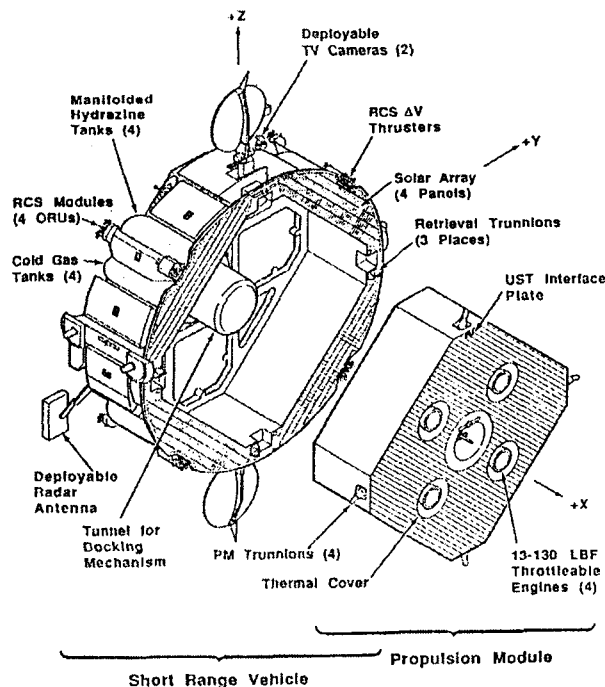


Figure 12 - Orbital Maneuvering Vehicle

Weight Summary (kg)	SRV	PM	OMV
Burnout w/ Max. Residuals	3,475.	1,300.	4,775.
Maximum propellant:			
Bi-propellant		4,082.	4,082.
Hydrazine	535.		535.
Cold Gas (N ₂)	165.		165.
TOTAL	4,085.	5,382.	9,467.

Width = 5.9 m
Diameter = 4.5 m

Table 4 - OMV Weight & Size Summary⁴

Upgraded ELV Stage

Upgrade of the present final stage of the ELVs, such as the high energy Centaur stage of the Atlas IIA, has several advantages as well as comparable disadvantages. The advantages would include elimination of a docking procedure and round trip propellant requirement, and utilization of existing systems (RCS, communications, etc.). However,

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the cost for the addition of a cold gas system for proximity operations, the isolation of hazardous systems, "smarts" to meet CCZ requirements, power for extended mission life, and the addition of a deorbit system could be prohibitive. A detailed analysis of each ELV's stage modification requirements will be needed to fully determine its merits.

Small Upper Stage

Current small storable propellant upper stages, such as the CRAF propulsion module and the MX fourth stage, lack the capability to meet the requirements of the CCZ. Most of the propulsion modules rely on the spacecraft's avionics, where others were designed for a different type of mission. The advantages and disadvantages described for an upgraded ELV final stage would be the same for these stages. The small upper stages offer an additional advantage in higher mass fractions, but much of that could be negated with the addition of required systems. Solid propellant rocket motors such as the PAM series lack the controllability and accuracy for a space station logistics mission.

New Transfer Stage

The development of a new transfer stage is generally a high cost option. But, if ELVs are to become a main element in the support of the space station for the next few decades, there may be a substantial life cycle cost benefit. The incorporation of an automatic rendezvous system using advanced technology could be extremely beneficial in reducing the workload of the station crew. ESA is exam-

ining the possibility of developing an Ariane Transfer Vehicle for the Ariane 5 delivery stage to support the space station. This new stage is based on the current program's L-5 upper stage.

Carrier Options

The current Space Station Freedom program has four main NSTS configured logistics carriers (Figure 13). The carriers consist of the Pressurized Logistics Module (PLM), Unpressurized Logistics Carrier (ULC), Animal/Specimen Transport System (ASTS), and the Japanese Experiment Logistics Module (ELM). The PLM will provide a pressurized environment for launch and return of supplies that will be utilized inside the space station modules, such as: crew, food, and clothing supplies; housekeeping; material processing equipment; and spares. The ULC, consisting of fluid and dry cargo subcarriers, will be responsible for delivery of attached experiments and spares for the external elements of the station. The ASTS will support specimens for the life science experiments with critical prelaunch and postlanding access requirements. The ELM is a separate Japanese element consisting of two sections, pressurized and exposed. The ELM will provide support for most of the Japanese requirements.

The ELM is the only logistics element being designed for possible launch on an ELV (H-II). As related to the PLM, ULC, and ASTS, only the ULC could be easily configured for an ELV launch, due to its minimal support requirements. The stringent demands of the ASTS makes an ELV launch highly

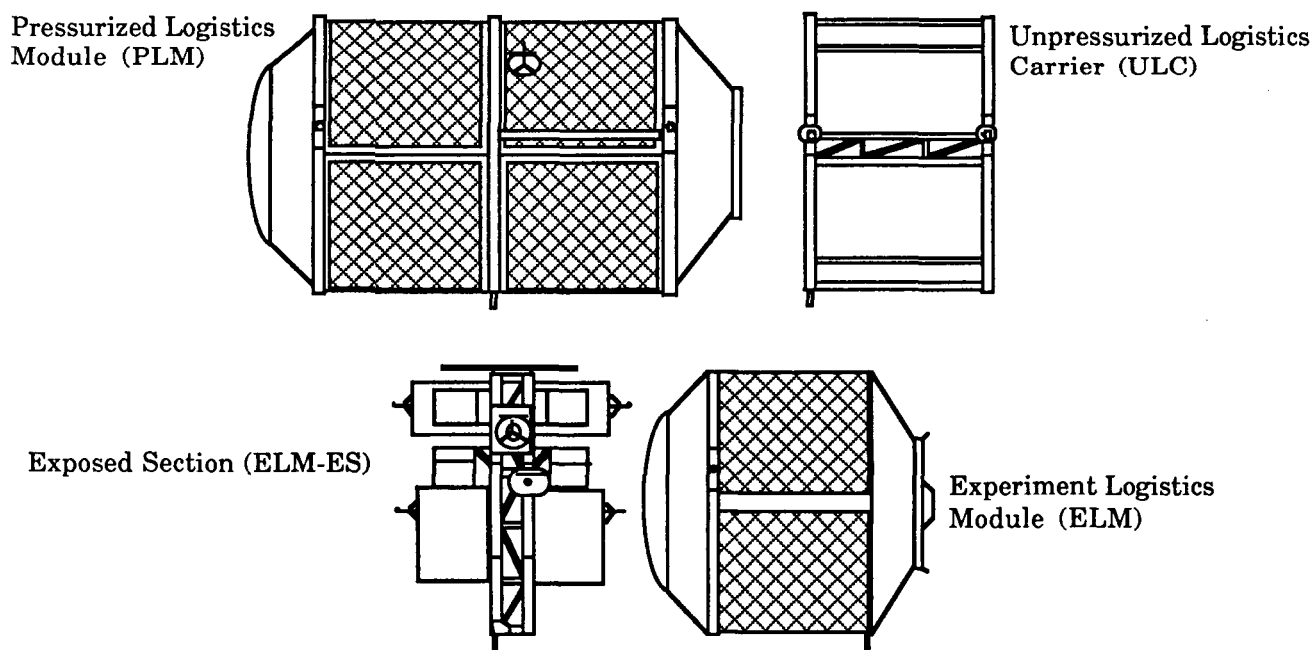


Figure 13 - NSTS Logistics Carriers

improbable. The PLM requires 1.2 kW of power along with comparable thermal control, as configured for a NSTS launch, commanding a substantial power system weight penalty for an ELV delivery.

NSTS Compatible

ELV delivery of current logistics elements, though desirable from a cost and operations standpoint, may not be the best solution. The NSTS logistics elements are being designed to be reusable and to provide return cargo capability. Since the NSTS will be transporting other logistics carriers, it's doubtful whether the NSTS will be able to efficiently manifest a return-bound ELV-launched logistics element. Also, the logistics element must have trunnion and keel pins for integration into the Shuttle for earth return. These pins will protrude through "NSTS compatible" ELV payload envelopes, except Shuttle-C. This would require unique modifications to the payload fairings or on-orbit pin installation, which may be an unacceptable procedure.

ELV Unique

The use of an expendable vehicle may warrant logistics elements that are also expendable. The carrier could provide for a safe disposal of low priority items (trash, used equipment, etc.) by a controlled reentry and burn-up. A new ELV carrier must maintain provisions for the transport of standard racks (pressurized) and cargo subcarriers (unpressurized). Impacts to the space station operations must be minimized to keep logistics element processing as common as possible, both in ground processing and handling in space, to reduce costs and complexity. Some of the unpressurized cargo does not lend itself to subcarrier delivery due to packaging constraints and must be evaluated on a case by case basis.

Two options exist for development of an ELV logistics carrier: (1) configure the carrier within payload fairing constraints, or (2) eliminate fairing and incorporate launch environment protection into the carrier structure. A carrier developed to be launched within the fairing could be designed for various launch vehicles, follow NSTS carrier design philosophy, and reduce development cost. Elimination of the fairing would require the carrier's structural design to meet specified vehicle constraints (length to diameter, aerodynamic profile, launch pad clearances, etc.). These constraints may cause the carrier to be vehicle-dependent, but will offer increased volume and net payload capability. The main driver will be to keep logistics carrier costs to a minimum without sacrificing safety or reliability.

Return Considerations

The NSTS return capability is approximately 1000 kgs higher than its Freedom launch performance (Table 3). This alleviates some of the down weight transportation problems. However, augmentation of the NSTS lift capacity by any method without increasing landing weight capacity will create a storage problem on Freedom. Six percent of the total down weight mass consists of pure trash and useless replacement units. An additional 11% of the cargo is desirable for return, but could be discarded if required. These numbers indicate mass build-up on Freedom can be curtailed by developing an efficient and environmentally safe disposal system. Various options exist for disposal of trash, such as atmospheric burn-up, safe orbit storage, or earth escape, the most probable method being atmospheric burn-up from a performance and safety standpoint. This can be achieved by various methods: (1) extend the delivery transfer vehicle's mission to incorporate disposal requirements, (2) use inexpensive solid rocket motors, or (3) apply momentum transfer techniques (tethers) as technology matures. Impacts to the total logistics system are not insignificant for trash disposal and must be accounted for in all logistics planning.

Commercial Opportunities

The potential for commercial opportunities for space station logistics support is self evident. The three decades of support Freedom will require constitutes a need for efficient, low cost transportation systems. With many of the launch vehicles providing launch vehicle services, an extension to a total logistics support package has a high potential for success. Development of requirements and guidelines will assist the commercial entrepreneur in planning for the future.

Summary

The Space Station Freedom program should examine the operational procedures for ELV logistics support. The potential ELVs, their payload configuration, transfer system, space station operations, and disposal options must all be evaluated and integrated into the entire logistics system to determine the most optimal approach for a flexible, cost effective program. Early definition of program impacts will alleviate possible high cost modifications to Freedom and undesirable constraints on the launch systems. Development of a more resilient space transportation capability, based on a mixed fleet, will permit an enhanced level of productivity while offering an opportunity for evolutionary growth.

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Report Documentation Page

1. Report No. NASA TM-101947		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle Expendable Launch Vehicle Transportation for the Space Station				5. Report Date	
				6. Performing Organization Code	
7. Author(s) Robert R. Corban				8. Performing Organization Report No. E-4636	
				10. Work Unit No. 572-09	
9. Performing Organization Name and Address National Aeronautics and Space Administration Lewis Research Center Cleveland, Ohio 44135-3191				11. Contract or Grant No.	
				13. Type of Report and Period Covered Technical Memorandum	
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546-0001				14. Sponsoring Agency Code	
15. Supplementary Notes Prepared for the 39th Congress of the International Astronautical Federation, Bangalore, India, October 8-15, 1988.					
16. Abstract <p>Logistics transportation will be a critical element in determining the Space Station Freedom's level of productivity and possible evolutionary options. The current program utilizes the Space Shuttle as the only logistics support vehicle. Augmentation of the total transportation capability by expendable launch vehicles (ELVs) may be required to meet demanding requirements and provide for enhanced manifest flexibility. The total operational concept from ground operations to final return of support hardware or its disposal is required to determine the ELV's benefits and impacts to the Space Station Freedom program. The characteristics of potential medium and large class ELVs planned to be available in the mid-1990's (both U.S. and international partners' vehicles) indicate a significant range of possible transportation systems with varying degrees of operational support capabilities. The options available for development of a support infrastructure in terms of launch vehicles, logistics carriers, transfer vehicles, and return systems is discussed.</p>					
17. Key Words (Suggested by Author(s)) Launch vehicles; Space stations; Operations; Space logistics; Payload transfer; Space shuttles; Space Transportation System				18. Distribution Statement Unclassified - Unlimited Subject Category 16	
19. Security Classif. (of this report) Unclassified		20. Security Classif. (of this page) Unclassified		21. No of pages 13	
				22. Price* A03	